This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

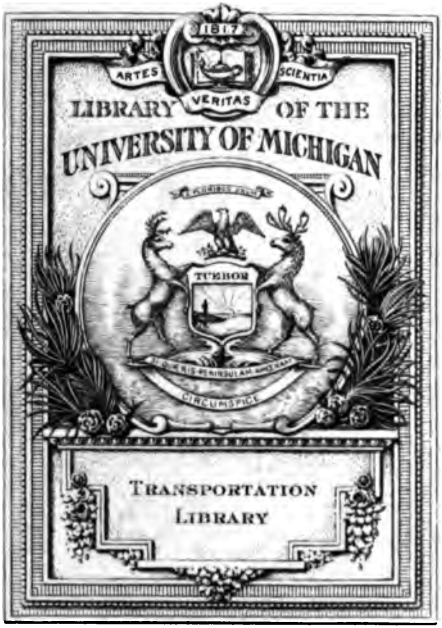
About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

TRANSPORTATION
LIBRARY
TF
216
.B97

A 757,604 DUPL

LINE
AND
SURFACE



LIBRARY OF THE
UNIVERSITY OF MICHIGAN

TRANSPORTATION
LIBRARY

Library

TF
216
.B97

LINE
and
SURFACE

A PRACTICAL TREATISE ON LAYING OUT AND MAINTAINING THE ALIGNMENT AND SURFACE OF RAILROAD TRACK

TRANSPORTATION LIBRARY
UNIVERSITY OF MICHIGAN

BY
MOSES BURPEE
Chief Engineer Bangor & Aroostook R. R.

Published by
THE RAILWAY REVIEW
1305 Manhattan Building, Chicago
1906

MU

PREFACE

The subject matter of this book had its origin in a series of circular letters of instruction prepared by the author for his own trackmen. These were later revised and published as a series of articles in the Railway and Engineering Review. The treatment of the subject is simple and practical, and at the same time theoretically correct. Engineers will find it interesting from this standpoint, the method of imparting such instruction in the best way being an important and ever-present problem.

CONTENTS.

PAGE

Chap. I—Correcting Alignment on Curves...... 5

Chap. II—Method of Middle Ordinates..........14

Chap. III—Transition Curves..................18

Chap. IV—Running Off Elevation...............23

Chap. V—Compromise Run-off for Curve Elevation 28

Chap. VI—Curved Graduation of Elevation......34

Chap. VII—Curved Graduation Throughout......39

Chap. VIII—Application of Transition Curves....45

Chap. IX—Heaving Track......................53

Chap. X—Properties of Ballast Material.........57

Chap. XI—How to Maintain Line and Surface...61

LINE AND SURFACE

CHAPTER I.

CORRECTING ALIGNMENT ON CURVES.

Railroad line is originally established with the engineers' transit instrument and the chain, and with these it is possible to run a line absolutely straight or with curvature of any degree. On roads where traffic is heavy, and a first-class track is imperative, it pays to use instruments for the purpose of defining the line, but on many roads engineers are not employed solely for this purpose, and have not sufficient time along with their other duties to attend to track details fully. In many circumstances, these are left almost, if not entirely, to the trackmen. In either case, and especially in the latter, some knowledge of the properties of curves is very useful. I believe any man can easily learn, if he does not already understand, the principles which are hereafter explained.

You have somtimes, no doubt, noticed the disagreeable motion of a car running around a curve in which there are alternately sharp and flat places. This can be remedied by lining the curve with perfect uniformity, and by making uniform and proper elevation on the outer rails to agree with the curvature. You can imagine how much extra wear and tear a train suffers, on badly lined curves, by the swaying of the cars, twisting the frame and wrenching the couplings, and so on. Besides this, it must, no doubt, cost more in engine power to pull a train over badly lined track. How much extra power is needed cannot be guessed, but with proper appliances can be measured. Yet it is not necessary to know, for we can safely assume that it is cheaper to move loads on good tracks than on bad, and this is one good reason, in addition to that of the difference in wear and tear, for keeping track in the best possible condition.

Still another and perhaps the most important of all in an economic sense is the fact that the speed of trains may be greatly increased on good track, as compared with bad—thus enabling the transportation of larger quantities of freight and more passengers with the same number of engines and cars. By far the greatest consideration of all is that of safety, which is, of course, enhanced by all track improvement. Therefore, inasmuch as an important part of the trackman's work is to reduce the friction and expense of moving traffic over the road, it is important for him to know and apply the principles necessary to good work.

In railroading, line is either straight or curved. Technically, straight line is called tangent, and for convenience and brevity we will use that name. Curves are commonly spoken of as flat and sharp. but for definite designation when it is necessary to know just how flat or sharp they are, we speak of them as being of a certain number of degrees. A one degree curve changes direction one degree each 100 feet, and two degree curve twice as much, a ree degree curve three times as much, and so on.

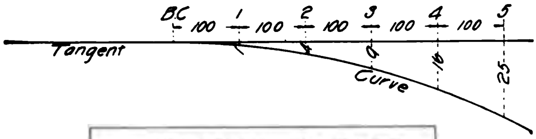
The point where tangent ends and curve begins is called Beginning of Curve, or simply B.C, and end of curve E.C. The first 100 feet from B.C. on a one degree curve carries the line 10½ inches to one side of the direction of the tangent, and the same rate of curvature in 200 feet, about four times, and 300 feet about nine times. The distances between the prolongation of tangent and the line of curve are called tangent deflections. For a two degree curve any corresponding deflection is twice as much, and for a three degree curve three times as much as for a one degree curve, and so on. The simplest rule for finding the deflections up to a few hundred feet very closely is this: Extend the tangent beyond the B.C. and mark the end of first 100 feet from B. C. 1, the end of the second 100 feet 2, the third 3 and so on. Measure off the side on which the curve runs, at point 1, the deflection distance, equal to 10½ inches multiplied by the degree of curve; for point 2, square 2 (that is, multiply it by itself), and the product 4, by the deflection at 1; for point 3 use its square, 9, for the multiplier, etc.

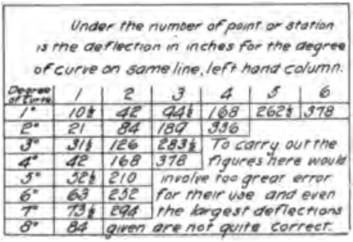
Table 1 and the sketch accompanying it will explain this, and also give deflections for curves one degree to 8 degrees up to a certain limit, within which there is a very small error, but beyond that limit the rule would not answer. On account of its simplicity it is worth remembering, and can be used very often when the means of finding correct curve points are not at hand.

It is important for the trackman also to carry a good line all the way around a curve. No matter how well a curve may have been originally lined, there are many ways for it to get out of line each year, and the longer it is left without re-lining with transit, the worse it is apt to become. There is, moreover, liable to be a settling of embankments, and on rough and sidelong ground this will carry the roadbed and track out of line so it can not be exactly lined to the original curve without throwing it too far from its bed, resulting in a defect which would be worse than that which we are trying to remedy. In such cases it is well to know how to smooth up as it were badly lined curves so there will not be any very sudden changes in direction, and with all due respect to instrumental work, I think it is not unreasonable to say that the section

— TABLE I —

—For finding tangent deflections of curves—
—near beginning or end—




Under the number of point or station is the deflection in inches for the degree of curve on same line, left hand column.

Degree of Curve	1	2	3	4	5	6
1°	10½	42	94½	168	262½	378
2°	21	84	189	336		
3°	31½	126	283½			
4°	42	168	378			
5°	52½	210				
6°	63	252				
7°	73½	294				
8°	84					

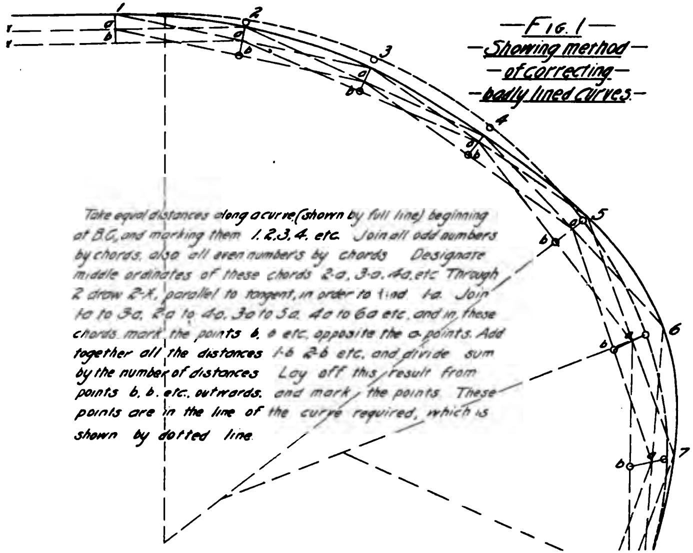
To carry out the figures here would involve too great error for their use and even the largest deflections given are not quite correct.

crew can, by the intelligent use of the following rule, do as good a job of lining with a fine cord and a pocket full of nails as an engineer can with a transit. The cord should be a few feet longer than two rail lengths and the nails about 6 or 7 inches long, wire, and about 15 or 20 should have small tag with letter A, the same number with letter B, and as many more blank ones will probably be found convenient.

Fig. 1 shows a method of correcting the line if a very badly lined curve. From point 1 to 3 it is sharper than it should be; from 3 to 5 flatter, and from 5 to 7 it is very much too sharp. For convenience it will be better to use the rail joints if the rails are all of equal lengths. If they are not, points should be measured around the curve, say 50 feet apart (in which case the cord must be 100 feet long), and the rail marked with chalk or otherwise at these points, 1, 2, 3, 4, etc., placing 1 at the beginning of the curve usually called B.C. Sight along the gage line of rail, first from 1 to 3, and place in this line opposite 2, one of the nails marked A. Then sight 2 to 4 and place a nail opposite 3, also marked A, and so on around the curve, sighting between odd numbers for the setting points AAA opposite even numbers, and sighting lines between even numbers for setting points A A A opposite odd numbers. These points may be designated as 1A, 2A, 3A, etc. In order, however, to find 1A, which is opposite the B.C, we need to draw a line backwards from 2 and parallel with the tangent. We may do this by sighting from 2 and finding a point outside the line exactly opposite 2, which will range with the rail along tangent, and measure the distance from the point to 2. Then lay off this distance at 1 for 1A. Then from 1A sight to 3A and in this line opposite 3A place nail marked 2B and sight from 2A to 4A, and opposite 3A set another nail marked 3B, and so on around the curve.

Next add together all the distances, 1B, 2B, 3B, 4B, etc., between gage line of rail and points B that will have been thus set, and divide by the number of the distances. The B points will lie in a curve which is very nearly true, and by measuring outwards from these B points the average as above found, we get the proper position for the rail, to which it should be thrown. When laying off the final points they should be marked by the blank nails; then the nails marked A and B should be removed and the new line tested in the same way that the rail was, and if the new ordinates 2A, 3A, etc., are found to be very nearly equal it may be as well to line the track to the new curve. However, it is possible if there is still considerable inequality in the ordinates, to reduce that inequality by repeating the operation, using the line marked by the blank nails as a starting line just as you at first used the rail. It sometimes is the case that the roadbed is not in good line and consequently it will not be possible to exactly line the track, and even one line of ordinates, viz.: those designated by A will give a line as good as can be used, and that although the B line will be nearer a true circle, it may move the track too much to one side of the solid roadbed.

The figure shows how a very irregular curve is



—Fig. 1—
—Showing method—
—of correcting—
—badly lined curves.—

Take equal distances along a curve (shown by full line) beginning at B.C., and marking them 1. 2. 3. 4. etc. Join all odd numbers by chords, also all even numbers by chords Designate middle ordinates of these chords 2-a, 3-a, 4a, etc Through 2 draw 2-X, parallel to tangent, in order to find 1-a. Join 1a to 3a, 2a to 4a, 3a to 5a, 4a to 6a etc, and in these chords mark the points b, b etc, opposite the a points. Add together all the distances 1-b 2-b etc, and divide sum by the number of distances Lay off this result from points b, b. etc., outwards. and mark the points These points are in the line of the curve required, which is shown by dotted line.

improved by only two lines of chords and ordinates. The dotted line is a true circle which very nearly, but not quite, strikes the points found. These points are the centers of the little circles. It is probable that one or two more lines would have brought it so near that the difference would have been almost imperceptible. It is not possible to draw a perfect circle in this way, but the oftener you correct what you have, the nearer the resulting curve is to perfection, and as you always have in starting, a curve which is pretty near, you will soon get one that is very nearly perfect and on which no defects in riding quality can be found.

You will see in Fig. 1 that a true circle extends from between 1 and 2 to 5, but that a circle of shorter radius (the line drawn to center) is required from 5 to 6, and of one of still shorter radius from 6 to some distance beyond 7. In the original curve there is considerable bulge opposite those points, and it would require a repetition of the process to draw that bulge in to a true circle. But sometimes curves are made originally of varying rates of curvature in different portions, and to change such to uniform curvature would be wrong. Curves having one portion of different radius from another portion are called compound curves, and are frequently used in rough side-hill country. It is scarcely possible for a trackman, or others to find the exact points where the curvature changes unless the original point is marked by witness stakes. The use of the above rule will show nearly where such points are, and it will improve or make the change from flat to sharp curvature a gradual instead of an abrupt one. The point of change or compounding can be detected by the changing length of ordinates, and when located the portions of the curve on either side should be treated independently of each other.

The above statement of the rule uses the gage line of the outer rail of curve to work by. It may be better to drive the blank nails along the center of the track as it is, finding them by the center mark on the track gage, and correct the line in the same way as above described. This will avoid working close to the rail, which might obstruct the setting of the points if the rail instead of the center of the track were used.

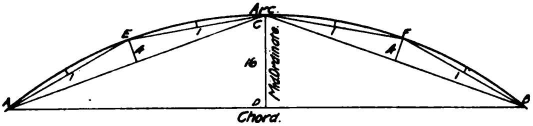
CHAPTER II.

METHOD OF MIDDLE ORDINATES.

Chapter I described a method for ascertaining if a curve is out of line and for correcting bad line in curves. In this chapter we shall consider another method of doing the same thing, and it may be a better way on quite short curves. Any distance along a curve may be taken, but, for convenience sake, the reason for which will be seen as we go along, it is better to take a distance which can be divided into eight equal parts.

Referring to the figure with Table 2, lay out chord AB and find D at its middle point, just opposite C, the middle of the arc. CD is the middle ordinate of arc AB. Again find chords and middle ordinates of halfarcs AC-CB, and of quarter arcs AE-EC-CF and FB. The middle ordinate of the half arc is one quarter that of the whole arc, and the middle ordinate of the quarter arc is one quarter that of the half arc, or one sixteenth that of the whole arc. Therefore, in order to make the curve AB uniform, measure off the proper ordinate lengths from the chords, using a quarter of CD at E and F for ordinates of half arcs, and a sixteenth of CD as ordinates of the quarter arcs. Remember that one end of the ordinate is on the middle of the chord or straight line drawn from end to end of arc; and the other end must be a point in the curve. In Table 2 chord length is in feet, and length of ordinates are given in inches.

TABLE 2.



The arc above represents a railroad curve 8 rails long, each of equal length, extending from A to B. Its middle ordinate is C-D. Divide arc into 2 halves, A-C and C-B, and also into quarters at E and F. Middle ordinates of half-arcs are ¼ length of that of whole, those of quarter-arcs are ¼ that of half-arcs. These values are marked on figure as 1, 4, 16.

TABLE OF ORDINATE LENGTHS.

Degree of Curve.	1	2	3	4	5	6	7	8	9	10
Middle Ordinate 60' Chord	1	1⅞	2⅞	3¾	4¾	5⅝	6⅝	7½	8½	9⅜
" " 66' "	1⅛	2¼	3⅜	4½	5⅝	6⅞	8	9⅛	10¼	11⅜
" " 50' "	¾	1⅜	2	2⅝	3¼	4	4⅝	5¼	5⅞	6⅝
" " 100'. "	2⅝	5¼	7⅞	10½	13⅛	15¾	18⅜	21	23⅝	26¼

For length of ordinate, look in column under figure representing degree of curve, and in same line as length of chord given in left hand column.

Note — The line for chords of 60' corresponds to two 30' rail lengths. That for 66' to two 33' rails.

This method will be found convenient for portions of a curve of 8 rail lengths in any curve up to 6 degrees, which will not bring the point D off the roadbed. For sharper curves it will be better to use some shorter arc; for instance, one composed of 8 times 25 ft., the ordinate of which will be about two-thirds that of the chord with eight thirties; or an arc of 8 times 20 ft., the ordinate of which will be less than half the same.

It, however, has this limitation, namely, that you cannot be sure, when you need to repeat the lining of successive portions of a curve such as is represented in the arc AB, Table 2, that you may apply the point A to the point B; that is, begin one arc where you left off the other, and that the curve will be uniform throughout the length of the two arcs. Should your curve be not a compound but a simple one, that is, one which has an equal length of radius, or equal degree of curvature throughout, it is very unlikely that any error at the point where the two arcs join each other will amount to anything serious, but should it be perceptible, it can be lined by eye without trouble. But you can test the line if there is any doubt, after you have run in two arcs in this way. Join the middle points of the two. This gives an arc the same in every way as AB. Figure 2 explains this, the arcs AB and BC each being equal in every way to the arc AB in Table 2, but not showing the half and quarter arcs, as they are not in this case necessary. A new arc EF is composed of one-half of each of the two arcs laid down and one end of its middle ordinate will be the point where the two join each other. If the middle ordinate is equal in length to the middle ordinate of either of the others, then the curvature is uniform for the length of the two arcs.

If, however, we find the ordinate F of different length from E, it indicates that curve is either out of line or is "compound." By referring to Figure 3 we see two arcs of a compound curve, joined at the point of compounding. Both these arcs can be lined separately by the rule with Table 2, but the middle ordinate must be of different length, and if we find that the middle ordinate D, Figure 3, of the arc made by taking a half each of AB and BC, is an average of E and F, it is proof that the curve throughout the two arcs is properly lined.

Figure 4 shows the two arcs each in perfect line, independently of the other, but not properly joined at B where the ordinate D is less than F or E. Figure 5 shows a case where D is greater than F or E. When D is of the proper length, as before described, the two arcs are said to be joined tangentially.

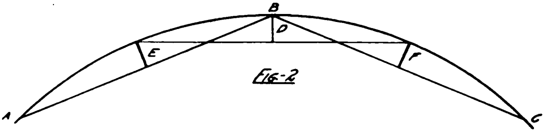


Fig-2

Middle ordinates E, D, & F, being equal, show that curvature is equal, from A to C.

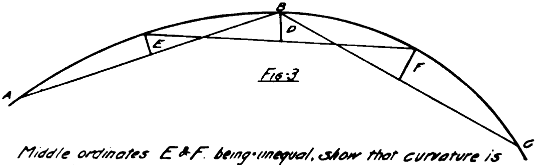


Fig-3

Middle ordinates E & F being unequal, show that curvature is not uniform, and for arcs AB & BC to be properly joined at B, the middle ordinate, D, must be an average of E & F.

CHAPTER III.

TRANSITION CURVES.

In passing from a tangent to a curve it is important to make the change gradually. This is done by the introduction of the process often called tapering off the curve. This has also by different persons been given the name of easement, spiral or transition curve. The latter name I think the best, and will use it hereafter.

The need for a transition curve lies in the fact that on all curves where trains are run at speed, it is necessary to raise the outer rail in order to give an inward inclination to the cars and prevent them from tipping outward dangerously or uncomfortably by the reason of the centrifugal force due to curve motion. Of course, this elevation of the outer rail must be made gradually, so that its tendency to raise one side of the car shall be only so fast as to be readily absorbed by the springs. The idea is to avoid the sudden and disagreeable sidewise motion which is noticeable where no transition is used.

Most of us remember the old rule used years ago which said you should give an inch elevation per degree of curve at the B.C. and E.C. and run this elevation off on the tangents at the rate of one inch in 50 feet. For instance, the elevation for the outer rail of a 1 degree curve should begin 50 feet before you get to the B. C. and gradually increase until you get the full inch just at the

B.C.; this rate to be maintained around the curve to the E.C. and then taper off to level in 50 ft. To work out this plan on a 3 degree or 4 degree curve causes the cars to tip badly just before coming to the curve. Usually three or four bad vibrations occur before settling down to smooth motion.

Several years ago it was thought, and by many strongly argued, that transition was entirely unnecessary, and perhaps with speed of 25 miles per hour it was. It might also be left out of the question with very easy curves, say one of 1 degree or 2 degrees. The usual practice of engineers then was to run uniform curvature from B. C. to E.C.

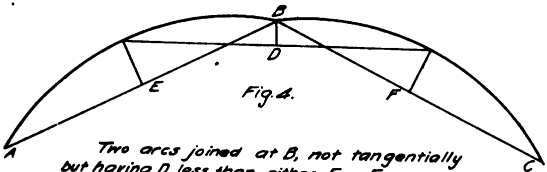


Fig. 4.

Two arcs joined at B, not tangentially but having D less than either E or F.

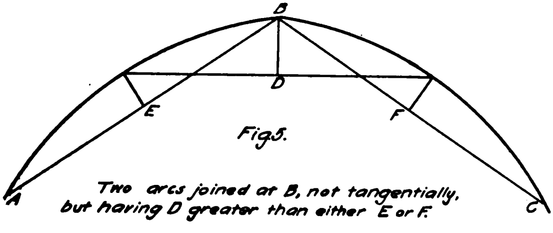


Fig. 5.

Two arcs joined at B, not tangentially, but having D greater than either E or F.

In many cases intelligent trackmen improved on this by tapering off the points of curves. Sometimes this practice was criticised by engineers, but not generally. It was admitted to be an improvement, but one which could be introduced without the engineer's help, and, in fact, there were no rules made for transition curves until recent years. There are two reasons for the growth of the idea and use of the transition curve. One, the extensions of railroads into country requiring sharp curvature, and the consequent use of sharp curvature generally; the other, the improvement of track and locomotives making high speed possible.

But while possible for the trackmen to line to a transition which improved the riding quality of road, it was even more difficult than to properly line an ordinary curve, and engineers, seeing the very general need which came along with fast speeds, heavy engines and cars, devised transitions to suit the purpose, and which could be laid off with instruments. There are many kinds, but they differ very slightly in detail, and are all alike in principle and operation. It is very easy to imagine that what is wanted is a curve which shall begin very gently and increase gradually until the same curvature is attained as that of the main curve, and for the elevation of track to begin just about where the transition does and increase proportionately so that there is always a perfect balance between the centrifugal force which on a curve makes the car lean outward, and the force due to elevation of outer rail which prevents it

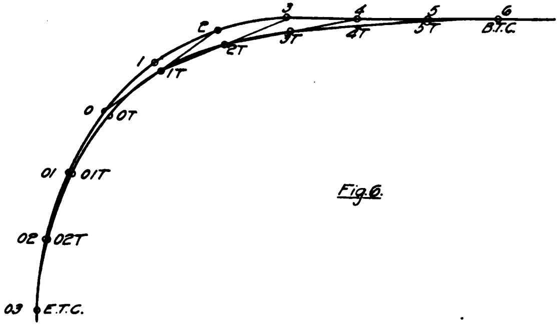


Fig. 6.

from doing so. Therefore, as the elevation must come in gradually from a level, the curvature should also be worked in gradually, and this is why the transition curve is necessary and has been devised.

Usually in new construction the whole curve is shifted inwards from the located line and the transition is fitted at each end. This permits the best and most rational arrangement. But on a line already built, it is not possible to throw the track off the roadbed so far as that method would require, but it is usual to apply such transition at the end of curve as can readily be done without throwing the track more than a foot or so. This must begin at some point on the tangent and end somewhere on the curve, and would probably never be much more than 250 ft. long, although the length may be such as circumstances require.

To get a rule for a curve which can be very readily put in by trackmen on the ground, I have devised that shown in Figure 6. I do not claim that it is so good a curve as could be run by transit, but it gives one which is correct in principle and varies only slightly in detail from the best possible. In Figure 6 lay off from the B. C. along the curve three chords of equal length. The end of the third chord is point 0. Continue marking off along the curve chords of same length as before, marking their ends 01, 02, 03. The last is E. T.C. Going back to 0, mark the chords before measured 1, 2, 3, along the curve and at equal distances 4, 5, 6, along the tangent. Six is B. T. C.

Draw a straight line 0 to 2, and mark the point on this line opposite 1, 1T. Draw line 1T to 3, and on it, opposite 2, mark 2T. Draw 2T to 4, and opposite 3, mark 3T. Draw line 3T to 5, and opposite 4, mark 4T. Opposite 5, lay off 5T at a distance from 5 equal one-fourth that from 4 to 4T. Next lay off the distance from 0 to 0T equal to nine-sixteenths that from 1 to 1T—01 to 01T equals to four-sixteenths, and 02 to 02T equal to one-sixteenth the same. The curved line passing from B. T. C. through 5T, 4T, 3T, 2T, 1T, 0T, 01T, 02T, and E.T.C., is the transition curve. The lengths of the chords may be such as will give satisfactory results, but in curves 6 degrees and less this length should not be less than 50 ft. unless the position of 2T is too far from the center of the roadbed. This is the greatest ordinate and therefore the length of chord may be determined very early in the process.

CHAPTER IV.

RUNNING OFF ELEVATION.

This chapter will deal with relations between transition curves and the change from the level track required on tangents to the elevated outer rail required on curves. It is seen from what is said in the preceding chapter that the getting of the proper elevation is as much a part of the transition as the lining of the curve itself, and this chapter will aim to demonstrate this. In doing so it seems necessary to show how this conclusion has been arrived at in actual practice by discovering the defects in the methods which, though useful under different circumstances, are not adaptable to the high speeds now used.

We shall first discuss the method once very commonly used of placing full elevation at the B. C. and gradually tapering it off along the tangent at the rate of 1 in. to 50 ft.

Figure 7 represents the two rails of a track as seen with the eye on the same level as the track, the outer rail of the curve being shown by the dotted line and the inner by the full line. The inclined portion A B of the dotted line shows the making or developing of the elevation along the tangent at the rate of 1 in. to 50 ft. It should be remembered, however, that the forces acting on the cars or engines to move them in any direction are concentrated at one point in each. This point is the center of gravity. In an engine this is about 7 ft. above the rails, and in loaded cars, except where the loads are of very heavy substance, probably about 6 ft. Therefore the elevation of one rail will move the path of the center of gravity to one side of the center by tipping the cars; and where the hight is 7 ft. the distance to one side will be about one and one-half times the elevation of the rail.

Figure 8 shows a track, a small portion of tangent and the adjoining curve, as seen from above, or as a plan view. It includes the portion in which the change from the tangent motion to the curve motion takes place, but without any transition curve applied, and with elevation made in the same way as Fig. 7. The outer rail is elevated, and the path of the center of gravity of the train is shown by a dotted line which is parallel to the curve, but at a distance about equal to one and one-half times the elevation to one side of the center line. This line, starting from the B. C., where it makes an abrupt angle with its direction on the curve, runs direct to the center of the track at the point where the elevation runs out, as shown by B. A., and there reaches the center line, where it makes another angle and thence follows the center of the track.

Now, suppose a train to be approaching the curve from the tangent; so long as both rails are on the same level, the center of gravity will be directly over the center of the track and in plan view it will be shown by the same line; but when ıe elevation of one rail begins the path of the nter of gravity departs at A from the center

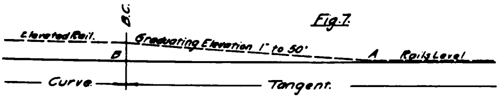


Fig. 7.

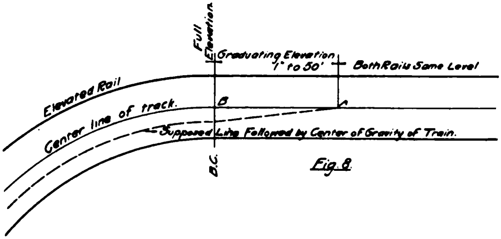

Full Elevation.
Graduating Elevation 1" to 50'
Both Rails Same Level
Elevated Rail
Center line of track.
B
A
Supposed Line Followed by Center of Gravity of Train.
B.C.

Fig. 8.

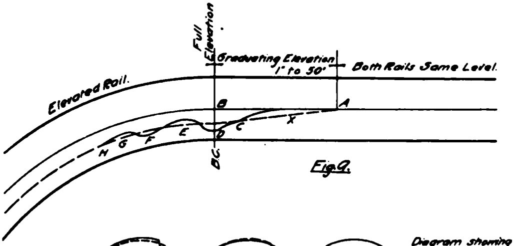


Fig. 9.

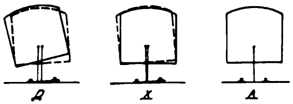


Diagram showing car at A, X, & D. Fig 9. True position of car shown by full lines. Theoretical, by dotted lines.

of the track, and its departure increases to the point where full elevation is attained; in this case at B. C., where it begins to follow a line parallel with the center line, but at one side, as shown above.

The law of inertia which tends to resist the movement of a body and also to resist its coming to rest when in motion applies to this case, so that the center of gravity of the train in motion on a straight line tries to continue on that line, and when a car arrives at A, instead of diverging immediately at the angle required by this method, still keeps on the tangent, owing to the elasticity of the springs until an amount of elevation has been reached sufficient to overcome its inertia, and to force the actual path of the center of gravity which we are now considering, to approach the line of its supposed path, namely, the dotted line A B. The car springs, which meantime have become more heavily loaded on the higher side of the car, in recovering also help to throw the car in that direction until the springs on the lower side resist and temporarily check further motion in this direction. This is illustrated by the first wave in the wavy line beginning at A and running towards the curve. This wave is shown as ending at C, where, because the two forces are nearly balanced, there is very little lateral motion, but increasing inclination of the car again disturbs the temporary balancing and gives a second impulse towards the low side, resulting in the second wave which reaches its hight at D. Here the curve begins, and the centrifugal forces, aided by the compressed springs on the low side, result in a sudden righting movement to the car. This by its inertia goes to E, a little beyond the true position (the dotted line), but as there are now two pretty nearly balanced forces the waves of lateral motion grow smaller and soon entirely cease, the waves F and G showing this gradual reduction. These latter waves coming after the car has reached the curve where elevation and centrifugal forces are balanced, are due to alternate action of the car springs.

CHAPTER V.

COMPROMISE RUN-OFF FOR CURVE ELEVATION.

In Chapter 4 we found why one method for graduating the elevation of the outer rail at the ends of curves is not a complete success. In this chapter we shall consider another method which has been used without transition curves. In this method the graduation of elevation takes place partly on the tangent and partly on the curve. Some make the rule to have two-thirds the amount of elevation at the B. C., graduating or running out at one inch to fifty feet on the tangent, and gaining the rest of the elevation at the same rate on the curve. The rate which I have adopted where the transition curve is not possible is to give one-half at the B. C., graduating on the tangent to nothing and increasing it on the curve until the full elevation is made, usually at the rate of one inch to fifty feet.

Figures 10, 11 and 12 illustrate the relation between the center line of the track and the path followed by the center of gravity of the cars in this method. It is plain that no such lurching motion is possible in the cars at any speed with this plan as there is with that described in Chapter 4, Figs. 7, 8 and 9. At the beginning of the curve half the amount of elevation is attained and the car has a slight tipping motion imparted to it which, by its inertia, would increase its inclination even without further elevation in the

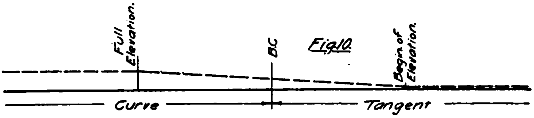


Fig.10.

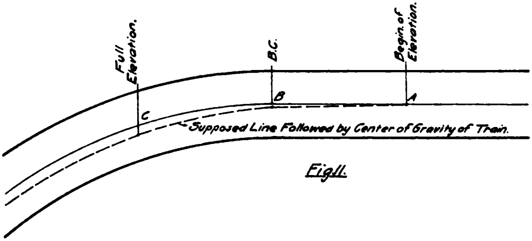


Fig.11.

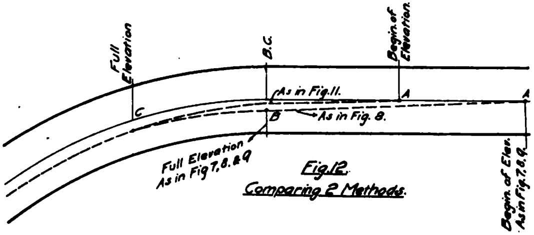

Full Elevation
B.C.
Begin of Elevation.
As in Fig.11.
A
A
C
B
As in Fig. 8.
Full Elevation As in Fig 7, 8, & 9
Begin of Elev. As in Fig. 7, 8, 9.

Fig.12. Comparing 2 Methods.

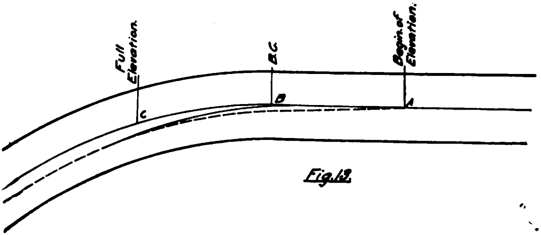


Fig.13.

track to help it, but at this point the curve counteracts the tendency to further inclination of the car and the two, balancing each other, allow the car to run with an even pressure on the springs and without any greater or less inclination than the track gives it. It is true that at the B. C. the elevation is not sufficient for the curvature, but we must remember two important facts which materially affect the necessary degree of elevation at this point.

One of these is that the car does not feel the full influence of the centrifugal force due to running on the curve while the rear truck is still on the tangent; and until both trucks are on the curve it does not need full elevation. When the rear truck has reached the B. C. the forward truck in the case of a passenger car will have reached a point where the elevation is about or nearly an inch greater, so that in reality the center of gravity of the car when the rear truck is at the B. C. and is just receiving the full effect of centrifugal force is at a point where the elevation is about half an inch more than at the B. C., and consequently aids to compensate for the deficiency in elevation at the B. C.

The other fact is that when a car in motion begins to run on the graduation of elevation in one rail there is a sudden raising of one side, and the impetus thus given to it is sustained even when the force is withdrawn. The force in this case is not the elevation itself, but the increasing of elevation which tends to tip the car more as it proceeds towards the point where elevation is full.

In other words, while the car is running up along the graduated rail towards the full elevation there is a greater force tending to throw it against the low rail than when running on track where one rail is constantly higher than the other by an unvarying amount. Therefore, this force inclining the car toward the low rail should be taken into account in running elevation into and out of curves and is very well provided for in the method here recommended; viz., half elevation at B. C., the rest gained at the usual rate after striking the curve. Referring to Figures 10, 11, 12 and 13, you will find illustrations of the above principles.

Figure 11 shows in the dotted line the supposed path of the center of gravity of the cars, or the path it would make if there were no springs in them, and also by a full line, the center of the track itself. You will see that there is not any abrupt change in directions at A, B', and C, as there are in Figure 8 at A and B. Figure 12 shows the corresponding lines of Figure 8, and Figure 11, side by side for convenient comparison. Inasmuch as the changes of direction of the moving load are made more gradually there is a corresponding improvement in the riding of the cars.

Figure 13 shows also the supposed path of the center of gravity of the cars and the actual path of the same, due to their springs permitting a different motion in the body of the car from that in the truck. At first there is a tendency for the center of gravity not to be affected by the change in direction at A required by the beginning of elevation. When, however, the elevation increases to such an extent as to be noticeable, which will probably be near the time the forward truck has reached the B. C., an inward tipping motion begins, but at about the same time the curving motion begins also, and the centrifugal force is gradually applied and counteracts the inward inclination due to increasing elevation and compressed springs on the high-rail side. The car is now in a position where, tending in one direction, the centrifugal force, and therefore the tendency of car to tip outwards, is on the increase. On the other hand, the elevation is increasing and along with it the spring pressure over the outer rail, which, with the momentum of inward tipping motion due to increasing elevation of the outer rail, tends to balance the centrifugal force and maintain a smooth motion in the cars. The improvement over the method of Chapter 4 is due to bringing the opposing forces into play at the same instant rather than one following the other, which results, as shown in Chapter 4, in excessive alternate swaying motion.

It would take time to make a scientific demonstration of the above, but I think the principle is quite simple and will easily be understood. The exact proportion of the full elevation which should be given at the B. C. may be subject to local conditions and is rather difficult to exactly determine, but we can be sure that the rule of one-half is a great improvement over the practice of full elevation at the B. C. Careful observation after its application may determine in some cases the advisability of slight change of the proportion of elevation at the B. C., but it is likely that no great change will ever be found necessary. It will also be noticed that the actual path of the center of gravity of the cars will come pretty near to a transition curve, and it is this we want rather than to make the wheels follow the same. It is seen that this path here is determined partly by the springs, while it would be better not to use them for that purpose unless unavoidable.

We must remember that we are not to consider this method for use where a regular transition can be applied, but in places where none was allowed for in the construction of the road, and where it could not now be applied without great cost.

This method should be considered as an improvement over that discussed in Chapter 4 or as a stage in the development of the ideal run-off.

CHAPTER VI.

CURVED GRADUATION OF ELEVATION.

The subject of this chapter is similar to that of Chapter V. The method of graduation or increase of elevation is a modification of the one there described.

By referring to Fig. 14, you will see that it resembles Fig. 10, in that half the amount of elevation is made at the B. C., but instead of beginning it at A and having it reach full elevation at B, we have rounded off the abrupt angles at A and B so as to avoid even small changes in direction, such as is shown by Fig. 11, Chapter 5.

A result approaching this was effected by the method of Chapter 5, but even though an improvement over the one of Chapter 4, it is not quite free from decided, though small, changes of direction. In moving bodies there cannot be any immediate or sudden change of direction from one course to another without producing a stress within the body, but when the change of direction is made gradually or through an easy curve, the stress is distributed both in time and distance and is not noticeable. It was shown in Chapter 4, Fig. 9, that the change of direction due to elevation in track at A did not immediately produce a change in the direction of the car, but that the springs over the elevated rail were compressed until by the combined force of the springs and inclined position of the rails, the inertia of the car,

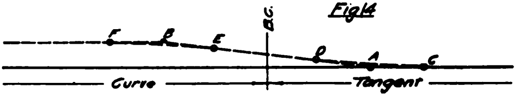


Fig.14

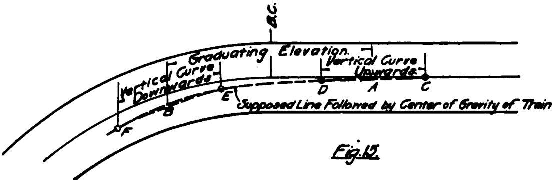

B.C.
Graduating Elevation.
Vertical Curve Upwards.
Vertical Curve Downwards.
D
A
C
E
B
F
Supposed Line Followed by Center of Gravity of Train

Fig.15.

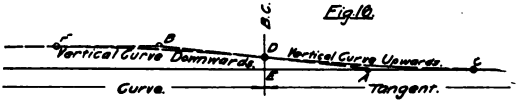


Fig.16.

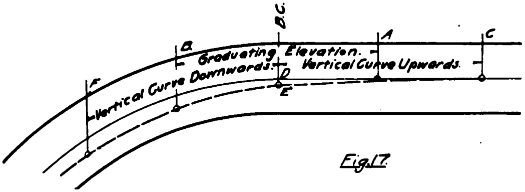


Fig.17.

which at first tended to continued motion in direction of the tangent, was overcome and the car was thrown towards and finally beyond the correct position, its motion on account of action of springs being along a curved line. Without the aid of the springs the stresses on cars from the sudden changes of direction as above described, would soon cause their destruction.

Here we have the choice of curving the path of center of gravity by placing the duty on the springs or on the track. The latter is cheaper and better. I think it is quite plain that Chapter 5, Figs. 10 to 13, show that much less spring work is done in passing through the graduation of elevation than had been done by the method of Chapter 4, and this simply by an arrangement that provides for a less abrupt change in direction of the path of center of gravity of the cars, and, therefore, with less tendency for the car to be impelled in some other direction by its inertia, than to follow the path determined by the rail, as shown by Fig. 9, Chapter 4.

Therefore the rounding off of beginning and end of graduation, as shown in Fig. 14, will be followed by beneficial results, in that it causes the center of gravity of cars to follow a curved path without the help of the springs. By examining Fig. 15, you will see at A and B, the angles of change in direction when these curves are not used and also the curve CD made to round off the angle A, and the curve EF made to round off the angle B. If you will refer to Fig. 13, Chapter 5, you will see that the curve of the path of the car's center of gravity begins at B, and is produced by the springs, and although answering the purpose fairly well for trains of moderate speed, and a great improvement on older methods, is not so good as that here described.

Referring again to Fig. 15, you will see that instead of the change in direction beginning at A, the introduction of the curve causes it to begin considerably earlier, but with a very gradual change, so that the full rate of graduation is not made until we pass A, and come to D, the end of the curve used for the rounding of angle A. The straight rate of graduation is then kept up until the point E, where the curve begins which is to round off the angle B, and gradually lessens it until it blends into the full elevation at F, without any perceptible shock. You will see that this method of making the graduation of elevation increases the distance and time, both of which are important factors in reducing stresses consequent on change of direction in heavy bodies. The increase in length of graduation shown in Figs. 14 and 15, is about 50 per cent, and I have described it for the purpose of making it easier to understand a more complete method shown by Figs. 16 and 17. In Figs. 14 and 15 the part of the straight graduation between D and E is unchanged and remains the same as laid out from A to B. In Figs. 16 and 17, we suppose a beginning and end of graduation at A and B, but we introduce curves which meet at the B. C., so that the curved graduation which we are using touches the straight graduation nowhere except at the B. C., where the curve EF begins. We must know, of course, the full amount of elevation to be used and, therefore, the length of straight graduation AB. The length of curved graduation is double this, because the beginning of curved graduation is at C, and AC is equal to AD, and the end is at F, and BF equals BE. D and E are at the same point, namely, the B. C., where one-half the elevation is used. The proportions of elevation to be given along the curved graduation at different points are as follows:

At the beginning C—None.
At A—One-eighth (⅛) of the whole amount.
At the—B. C.—One-half (½) of the whole amount.
At B—Seven-eighths (⅞) of the whole amount.
At F—The whole amount.

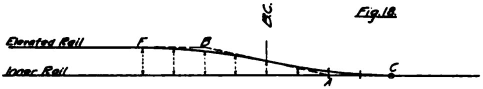
CHAPTER VII.

CURVED GRADUATION THROUGHOUT.

In continuation of the remarks toward the end of Chapter 6 regarding the graduation of elevation for the outer rail of the curve, we will again refer to the method which uses curved graduation throughout. The first half, an upward curve rising from the level rail, and the last half, a downward curve joining the fully elevated rail in a direction parallel to grade of the road. Where the upward and downward curvatures join each other, which in the method we have adopted is at the B. C., the rate of graduation is greater than at any other point, and is, in usual practice, 1 inch to 50 ft.

Referring to Fig. 18, notice that the elevated rail is represented by the curved line CF and the regular rate, or straight graduation, by the dotted line AB. The line of figures 0 to 8 under the diagram refer to the points where the ordinates of elevation are made or to the ordinates themselves. The length, or, as we may say, the height, of the ordinates depends on the degree of curve, and will be found in Table 3, allowing the amount prescribed by our rules; namely—15-16 inch per degree. There are exceptions to this, for in 1 deg. and 2 deg. curves the table gives 1 inch to the degree. The additional 16th or 8th of an inch in these cases would not be noticeable where the elevation is so small, even if it were possible to

Fig. 18.



Elevation Ordinate Number	8	7	6	5	4	3	2	1	0	
" " Value in Fraction	100	31/32	7/8	23/32	1/2	9/32	1/8	1/32	0	These figures apply to ordinates above.
" " " Decimal	100	97	.875	72	.5	.28	.125	.03	0	

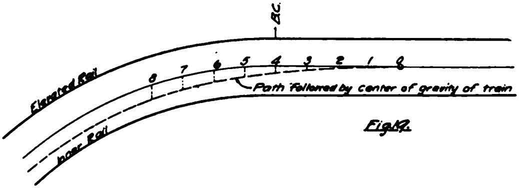


Fig. 19.

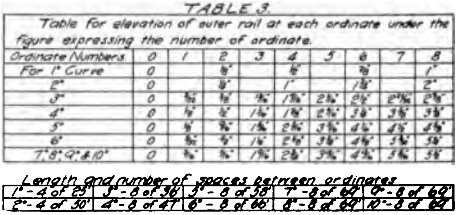


TABLE 3.

Table for elevation of outer rail at each ordinate under the figure expressing the number of ordinate.

Ordinate Numbers	0	1	2	3	4	5	6	7	8
For 1° Curve	0		1/8"		1/2"		7/8"		1"
2°	0		1/4"		1"		1 3/4"		2"
3°	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4°	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5°	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6°	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7°, 8°, 9° & 10°	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Length and number of spaces between ordinates

1° - 4 of 25'	3° - 8 of 36'	5° - 8 of 58'	7° - 8 of 69'	9° - 8 of 69'
2° - 4 of 50'	4° - 8 of 47'	6° - 8 of 66'	8° - 8 of 69'	10° - 8 of 69'

work so close in surfacing. In 6 deg. curves the elevation used is a little less than the rule. In curves 7 deg. to 10 deg. the amounts are equal, because when the elevation is so great as in these curvatures the amount of inclination in the cars is excessive and uncomfortable unless at higher speeds than usual on such sharp curvature. It is well to remember here, that within a certain limit the elevation does not increase in proportion to speed, but in proportion to square of speed; that is, suppose at 40 miles per hour you need 2 inches elevation on a 2 deg. curve, at one-half the speed you would want one-quarter that elevation, or ½ inch; the square of 40 being 1600 and the square of 20 being 400 or one-fourth. An exception to the rule is necessary, therefore, in very sharp curves, for two reasons, viz: great elevation shifts the load of the car too far to one side, overloading the springs and producing bad effects on the low rail; and, the general and safe practice of reducing speed on sharp curves.

The length also of the space between the ordinates depends upon the degree of the curve. For the length of straight graduation it is usually 50 feet for each inch of elevation, and in the curved graduation, Fig. 18, it is, as explained in Chapter 6, twice the length; therefore, the total length in feet of the graduation is equal to 100 multiplied by number of inches in elevation. In 1 deg. and 2 deg. curves we make only four spaces, but on curves sharper than 2 deg. we make 8 spaces. The length of these spaces is shown at the foot of Table 3.

Although it is probably best not to make these spaces much shorter than the table gives, we can in exceptional cases do so. Such exceptions might be on curves which reverse, or where the tangent between curves of opposite direction is too short to allow the proper proportion of the graduation to be made within its length. Again, it has already been pointed out that the only place on the curved graduation where the rate is as great as the straight rate is at B. C., and even here, supposing the center of a passenger car with truck centers 40 feet apart to be over the B.C., one truck center will be 20 feet on the upward curve and the other 20 feet on the downward curve. The straight rate of graduation would in 40 feet amount to 13-16 inch, but on the curved graduation it will be, for reasons above mentioned, but 11-16 inch. True this difference does not amount to much, but I mention it more to point out the fact, so that the character of the graduation will be better understood.

In determining the length of spaces between the ordinates, we must consider the action of car springs, as these are the means used for easing the motion of cars over irregularities of track. The freight car of to-day has a base from center to center of trucks of about 30 feet; most are shorter and a few are longer, but we can use this in our consideration. At 50 feet to the inch the amount of graduation between centers of trucks as above would be 30-50 of an inch, or about ⅝ inch. The usual allowable working deflection in freight car springs is 1 inch. This does not take up the entire play, but as much as it should, as we never want the springs to come close together, for then they are useless. This deflection would in extreme cases permit 2 inches graduation in the distance between truck centers, or 30 feet. But we propose, as a rule, to use only 3-10 that amount rated at 1 inch in 50 feet. For passenger cars the springs are more flexible even than this, so it will be safe to say that a passenger car will go where a freight car will.

The conclusion we should draw from this is not that we should make our graduations as short as the car springs and the distance between trucks seem to indicate as allowable, but that we should be cautious in changing a rate proven to be safe. We also know from experience of cases which do not admit of the regular rate being used, that a quicker rate will work all right, but inasmuch as there is discomfort if not actual damage caused by cars tipping very much towards the low rail, there is good reason for making the graduation as short as practicable, and a good proportion of it on the curve itself. It is only by careful experimenting that the proper proportions are arrived at in such exceptional cases When these have been ascertained, adopt them generally in similar cases.

By referring to Fig. 19, which shows the track as seen from above, you will notice that the positions of ordinates are marked from 0 to 8, as in Fig. 18. Point 4 is at the B. C., but the center of gravity of the cars begins to make a curved path at 0, where the curved graduation begins and follows an easy curved line, blending naturally into the regular curve at 8, instead of at the B. C From 0 to 4, the wheels are still on the tangent, but owing to the curved graduation, the motion of the body of the car is in a curved line, and the centrifugal force due to this counteracts its tendency to tip over towards the lower rail. From 4, the B. C. of track, the rate of graduation diminishes, and this results in a diminishing rate in curvature of the path of the center of gravity of the car until it equals that of the curved track after the point 8 in reached, where the elevation is full; and from this point through the curve, the path of the center of gravity of the cars is parallel to the center of the track. This method of graduation effects a transition of twice the usual length of the graduation. Although not lined in the track and not affecting the wheels, it does affect the loads, and that is the principal thing. This transition curve in center of gravity path starts at 0. At the B. C. the rate of curvature is a half that of the curve of the track, and at 8 is equal to the same.

As before mentioned, it is not intended to make this take the place of a transition curve which should be built into the road, but it can be made to answer the purpose fairly well where none has been provided for, and the object of this, as well as previous chapters, is to enable trackmen to help themselves when circumstances require it.

CHAPTER VIII.

APPLICATION OF TRANSITION CURVES.

I propose in this chapter to briefly review the main points of the transition curves mentioned in the preceding chapters, and to describe one in common use.

Figure 20 shows a curve fitted with such transitions are are described in Chapter 3, and it is also similar to all the transition curves which are applied to track laid on a roadbed on which none was run before grading, but where the main curve runs from B. C. to E. C. on a true circular arc. On each end the transitions B. T. C. to E. T. C. are run, so as to begin the graduation of elevation at or near the B. T. C. and gradually increase it as the transition becomes sharper until attaining full elevation at E. T. C. The worst fault with this is that at the E. T. C. it must be a little sharper than the main or original curve.

The only way to avoid this is as shown in Fig. 21. The original curve is from B. C. to E. C., the outside curve. You will see that no part of this is used when the transitions are run in, but that the middle portion between B. T. C. and E. T. C. is a little inside and parallel with the original, and is therefore a trifle sharper than it, but the increased curvature is immaterial, and it has the advantage over Fig. 20 in the fact that there are no sharper places at the end of the transition than in the middle or main portion of the curve.

In the method of Chapter 7 the line followed by the center of gravity of the cars is similar to this, but that method comes far short of giving so good a result as this.

This transition begins with a short arc or chord of 1 degree, and is followed in order by arcs of 2 degrees, 3 degrees and so on. The arcs are of equal length in any one transition, but this length may be such as circumstances determine. Excellent results are obtained by 25 foot chords, which do not require a great distance or offset to separate

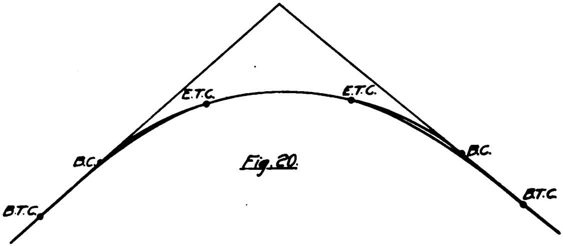


Fig. 20.

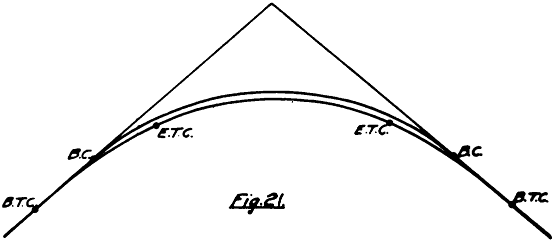


Fig. 21.

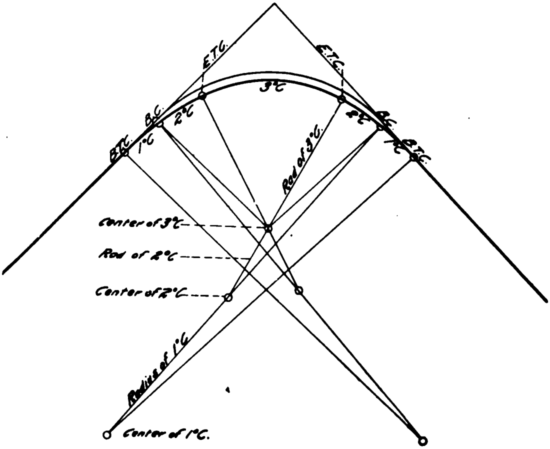
the inner curve from the original. If we are, however, obliged to graduate the elevation 1 inch in 50 feet and begin at the B. T. C. it would be necessary to mark the chords about 50 ft. long. In moderately sharp curves the difference in length of offset between this chord length and 25 feet would not be noticeable, but in curves of 5 degrees and 6 degrees it would be considerable and in some places the greater offset might be objectionable. Therefore I have adopted 25 feet as being the shortest length permissible and yet long enough to fairly accomplish the desired result. The rule for graduation with this is to have 1 inch elevation at the B. T. C. and to increase elevation at the rate 1 inch to 50 feet until full allowance was attained. This comes usually beyond the E. T. C. In other words the length of the graduation is greater than the length of the transition, and a part of the excess of length lies beyond each end. That is, it begins before the transition does, and ends after. The advantage of the 50 ft. chord lies in the transition and elevation beginning and ending at the same points.

The number of arcs or chords in the transition is one less than the number expressing the degree of curve. For instance, a transition of 3 chords is required for a 4 degree curve. The curvature thus progresses 1, 2, 3, 4. The first half of its length is on tangent and the last half on the original curve, thus for a 4 degree curve and transition chord 25 feet long, the total transition length will be 75 feet, and it will begin on the tangent 37½ feet before coming to the B. C. and end on the curve 37½ feet beyond the B. C. See Fig. 23.

Figure 22 shows a 3 degree curve with transition applied at each end, two chords—a 1 degree and a 2 degree. The radius of each chord is shown, and you will see that the center of any arc always lies in the radius of the preceding arc. When longer chords than 25 ft. are used, the ordinates are also longer, as follows: A chord of 35.4, ordinates twice; 43.3, three times; and 50 ft. four times as long as those for 25 ft.

The dotted diagonal line marked B. C. intersects the horizontal lines at their middle points, and the dotted vertical lines from these intersections point

FIG. 22



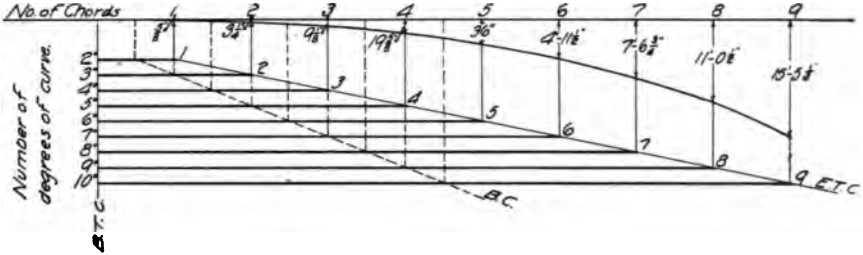
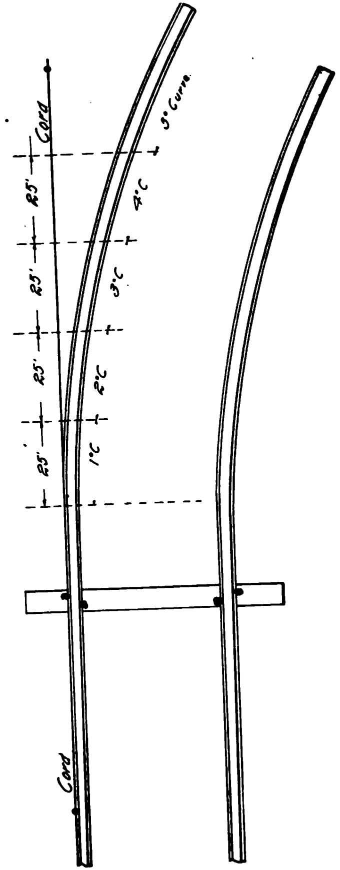


Fig. 23.

According as the length of chord varies the given tangent offsets must be multiplied by the following factors.

Chord	Factor
25.'	1
35.4'	2
43.3'	3
50.'	4

FIG. 2A



Note:- Not drawn to scale, but to illustrate the method of finding transition points for a 5° Curve.

to the position of the B. C. of a curve relative to its transition, showing that one-half the transition is on the tangent to the left of the B. C., and one-half on the curve to the right of the B. C. Where such a transition has been put into the track it can be relined by the following: The first thing to do is to find the degree of the curve by stretching a cord 61 ft. 8 inch. in length along the side of rail, so that middle of cord is about opposite the middle of the rail. This will give a better average middle ordinate than if it were taken near a joint, for the reason that if the track is not well lined the errors in line are usually greatest at the joints. The number of inches in the length of this middle ordinate is the same as the number of degrees of the curve.

Second: Stretch a cord along the outside of the outer rail on the tangent near the B. C. so as also to extend along the curve two or three rail lengths, but in a straight line. This cord may be in line with the base of the rail and just above the spike heads. See Fig. 4.

Third: From Fig. 23 find the ordinate or tangent deflection at the E. T. C. of the transition for this curve.

Fourth: Find the place where the distance between this cord and the base of the rail is equal to the ordinate or tangent deflection at the E. T. C. and stick a nail there on line with the tangent; and find if the other ordinates or tangent deflections between this and B. T. C. are of correct length, as shown in Fig. 23, measuring them at points 25 feet apart or at distances equal to the length of the cord used in the transition. See Fig. 24.

If so, the trial point taken should be adopted for the E. T. C. If not, this cannot yet be considered correct location for the transition, but rather a trial step in the process of finding it; so if you find the other tangent deflection ordinates too short for the rule, the trial E. T. C. must be moved further along on the curve, and if too long must be moved back towards the tangent. A few trials will decide the proper places for the transition, or at least the place where you can line in with the least disturbance of the track as you find it. This is the quickest way to locate the transition, as the E. T. C. is more easily found than the B. T. C., unless the points may have been marked by stakes. But we are supposing a case where trackmen must depend on their own resources. Once the transition line is marked out, the rail should be moved to it, and elevation properly given.

CHAPTER IX.

HEAVING TRACK.

The foregoing chapters have been devoted to the lining of curves; the elevation of the outer rail on curves; and the transitions at curve ends for the purpose of changing the motion of cars from tangent to curve, and curve to tangent easily and naturally, so as to avoid disagreeable and injurious shocks to cars and their contents. The speed at which it is desirable to run trains makes it a necessity that everything possible should be done to contribute to ease of motion.

While it is possible to put the track into just as good condition as any rule calls for, it is only by constant work and repairs that it can be maintained in good condition. In this and in other chapters to follow we will consider some of the things which counteract the trackmen's efforts to maintain perfect line and surface, and point out remedies which may be applied.

In summer, when the roadbed is dry, the track may be in the very best condition and yet the same track in winter may become dangerously rough. The reason for this is that any soil which contains moisture expands or swells in freezing. That which contains least moisture expands least, and that which contains most expands most. While it is absolutely dry no expansion takes place, no matter how cold the weather may be, but absolutely dry soil is almost never found. Frequently soils of different capacities for holding moisture are found close beside each other. Here there will be different rates of expansion every few feet, and as usually the only direction possible for expansion to occur is upward, we find what we call "heaving by frost" taking place and throwing the rails very much out of surface, but sometimes also out of line.

Should the soil be of uniform nature as to its capacity to hold moisture the heaving actually done would not be noticeable, because all had expanded uniformly. The need of shimming therefore is almost or entirely due to the variable nature of the materials in the roadbed under the ballast.

In grading the roadbed, owing to the uneven or wavy natural surface of the ground, the grade must frequently intersect this surface, sometimes being below it, as in cuttings, and sometimes above, as in embankments. Usually the earth or other material excavated in cuttings, where surface is above grade, is used in building the embankments on those portions of the ground surface which are lower than grade. The foot or two of surface is usually loam, while underneath the loam there is a bed of subsoil or hard pan. The surface loam is more spongy and will hold much more water than the subsoil, and consequently will, when frozen, be expanded more than the subsoil. Where a cut is more than 1 or 2 feet deep the grade usually passes into the subsoil; but where it enters and leaves the cut and also on the adjoining portion of the embankment which was made of loam from the nearest part of the cut, it will be found in almost all cases that the frost will heave the track badly. This is what really happens at each end of the cut and where the embankments are shallow. It is due to the larger proportion of frozon moisture in the soil at these parts of the road. At the same time it is noticeable that the part of the cut where the subsoil has been penetrated will usually have been heaved a very little or that the heaving is so uniform as to be not noticeable. The same is true of the adjoining embankment where its depth is sufficient to permit drainage, and is due to the very small amount of moisture contained in it.

It will be noticed in cuttings where there are very shallow places and where loam has been left in the roadbed that here heaving will take place to a greater degree than in deeper parts of the cutting. Also, in the shallow embankments of varying depths, that considerable heaving will occur where it is very shallow; that is, so shallow that the frost will penetrate to the loam under the embankment. Two things must combine to produce heaving, namely, moisture and freezing.

There are occasionally cuttings in which, even where quite deep, the track will heave badly. A large boulder, if the frost gets under it, will sometimes be forced up. Sometimes a solid ledge preventing drainage will cause it, though a seamy ledge with vertical strata seems to afford fair drainage which obviates it. Frequently, too, heaving is due to clay streaks in sand or gravel cuts.

The remedy possible to section men is, of course, to drain the road as well as possible. It is likely that a ditch 2½ ft. below the base of rail would almost entirely cure the trouble. But it is possible that even after this some places may have to be "dug out"; that is, the light porous soil, clay or boulders must be removed from under the track and replaced with gravel.

Plenty of ballast, of course, will do more than any other one thing except ditching. But ditching and digging out should precede ballasting in order to secure the best results.

CHAPTER X.

PROPERTIES OF BALLAST MATERIAL.

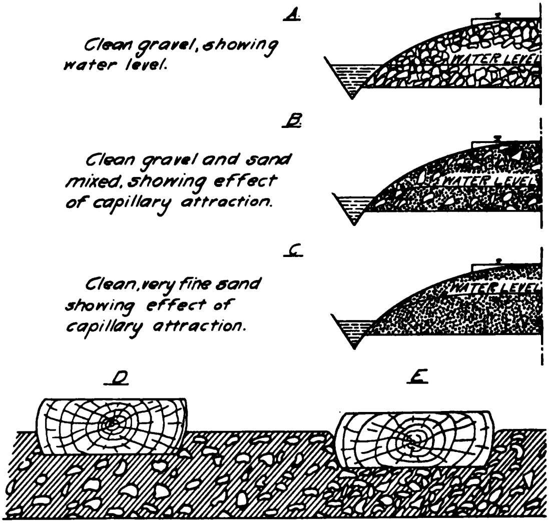
In the last chapter we considered the bad effect on line and surface from the heaving of frost of the roadbed containing moisture in varying quantities within short spaces. In this we shall see how moisture also affects roadbed injuriously in summer; but that instead of heaving above grade, as in winter, it allows it to settle below grade.

It is a well-known fact that clean, sharp sand or gravel makes a good, unyielding foundation for track, and that a small amount of moisture has very little injurious effect on it. It is not so, however, with clay or loam or with gravel containing a mixture of these, even when dry and much less so when wet.

Water drains very quickly through and from clean gravel or coarse sand, less quickly through fine sand, very slowly through the finest; while clay, which is composed of the same material as sand only ground to an extreme fineness, nearly always contains a small amount of moisture. But while it parts with its moisture very slowly it also absorbs it very slowly. Loam absorbs it quickly, but retains it a considerable time. The retention of moisture in soils is due to capillary attraction, so-called, a property by which liquids rise to and remain above their natural level into very small spaces, such as the pores of a sponge or the interstices between the fine grains of loam, clay or very fine sand. This characteristic is probably responsible for the muddiness of earthy mixtures in ballast and in roadbed which holds very small quantities of water in the minute spaces among the grains which compose the loam or clay.

When gravel is entirely free from any mixture of these earthy materials it will, as above mentioned, make a good foundation for track; but

Fig. 25.



A. Clean gravel, showing water level.

B. Clean gravel and sand mixed, showing effect of capillary attraction.

C. Clean, very fine sand showing effect of capillary attraction.

D. Gravel and clay or loam mixed showing condition when dry and without any weight or pressure.

E. Gravel and clay mixed and under pressure showing compressed condition of gravel under tie, caused by squeezing the clay out of the mixture by the weight on the tie.

when the spaces between solid grains are filled with earth material and the fine spaces in this again filled with water, so that it resembles mud, this earthy mixture becomes a lubricant to reduce the friction between grains of gravel, and the whole mass is then shifty and unreliable and will not hold up a heavy weight, but will flow from under it and allow it to settle. For this reason track laid on dirty ballast or badly drained roadbed settles quickly and is difficult to keep to surface, especially when wet.

Figure 25 is intended to illustrate the action of moisture in different kinds of ballast. Sketch "A" shows the best of gravel ballast without any mixture of sand or earth and in which the spaces or interstices are therefore as large as it is possible for them to be. This fact is favorable to the most rapid and complete drainage. If the grain is uniform or nearly so and nearly round, the percentage of space is at a maximum, and if the size of grain is such as to be readily tamped by a spade, it is probably as good ballast as can be. In "A" you will see that the water level is the same in the ballast as in the ditch, indicating perfect drainage.

In "B" the spaces between gravel grains is filled with sand. This is second in quality to "A," and the moisture line in ballast rises above that in the ditch.

"C" shows sand ballast, which is very common, and while it may answer the purpose fairly, it does not permit good drainage; and the moisture line is materially higher than in the ditch.

"D" shows a very inferior ballast, as the clayey portion between grains of gravel does not quickly dry out, and while moist it very quickly settles out of surface, as is illustrated in "E"; the reason for this being that the greasy or muddy clay is forced out from the gravel under the tie, as water is squeezed out of a sponge, the tie only coming to rest when the particles of gravel have come together by squeezing out all the intervening clay.

Even this material, however, it is sometimes necessary to use for want of better, but the only way to make it possible to maintain good surface is to provide the quickest possible drainage and to make the ditch low enough to thoroughly drain the road. It is not sufficient to ditch simply to the bottom of the ballast, or to sub-grade, but the bottom of ditch ought to be at least a foot below the latter, so as to drain it also.

Good drainage, moreover. by resulting in a dry and firm roadbed, makes a condition in which any repairs made are more lasting. Its effects are apparent in line and surface, but are also felt, if not seen, in a longer life for ties and rails, and we also may say for cars and engines; and who shall say not for the people who ride on them?

CHAPTER XI.

HOW TO MAINTAIN LINE AND SURFACE.

We now turn our attention to the care of track itself and consideration of the effects on it due to moving loads of engines and cars.

No matter how good track may be at first, it will wear out, and the joint being the weakest place, it will be the first to show wear. There is a liability for the joints to settle, and the rail ends to be depressed and surface kinked, as well as pounded down by the constant hammering of engine and car wheels. This is due primarily to the fact that the joint is the weakest place in the track, and, secondly, because, being the weakest place, it is depressed more under each wheel in passing than any other part of the rail. This drives down the ballast under the joint tie, but when the wheel has passed away from the joint it will spring up again.

This constant up and down movement of the joint tie produces the action very aptly named by trackmen "pumping," which, in fine or sandy ballast, not only settles it, but blows a portion of it out at the passing of each wheel, and allows still greater depression of joint. Related to this pumping and largely on account of it, there is a tendency for the third or fourth tie away from the joint either side to be slightly lifted by the leverage of the rail. As the joint goes down the rail becomes a lever and the tendency is to raise the third tie from the joint; but the rail's length and elasticity, as well as the weight of other wheels which may be on it, confine the lever action to within a short distance, so it is probable that only the third and fourth ties shall be lifted from their beds. This disturbs slightly the ballast along the sides of the ties, which, as they descend, is likely to be crowded under them, thus in time raising the tie slightly above grade and increasing materially the effect of the low joint.

The means which should be taken to prevent this is careful and solid tamping of joint ties. Doubtless the best means is to, first of all, tamp these ties the same degree of hardness as the others are to be tamped, but about a quarter of an inch above grade, then beat them down with a large wooden maul, after which the intermediate ties may be tamped at grade. The keeping of joints up to grade is of the greatest importance, not only for the riding quality of the track, but for the lasting quality of the rails.

Sometimes old and badly worn ties are responsible for defective line and surface, and while the rail appears to be both in good line and surface it may be temporarily forced out or down owing to insufficient support in the ties, and yet return to line and surface after the disturbing force has been removed. If this be the case, the track will ride badly, no matter how it looks. You are doubtless familiar with the fact that soft wood ties, and, particularly, cedar ties, become cut under the edges of the rail flanges, and the wood under the rail becomes pulpy, so that the tie will support the rail without any load, but will suffer a depression of one-fourth to one-half inch under load. In surfacing track it is necessary, in order to make it ride well, to adze out the softened wood, so as to bring a firm support close to the rail flange. In a similar way it is necessary, in order to have good line under a passing train, that the spikes should be kept tight against the rail flange. Good track not only looks well when not loaded, but keeps line and surface under working conditions.

In speaking of joints, it should not be forgotten that some of the new styles claim to be as stiff as the solid rail, and, therefore, if so, the ties under them should not be tamped harder than the others. It is necessary, however, with these to observe carefully their behavior and work accordingly.

Tie plates aid very much by preventing track from spreading and by saving ties from wear, and therefore are a great benefit to both line and surface.

No kind or number of appliances, however, can be made of full benefit without intelligent and careful use, nor can good track be maintained without the "eternal vigilance" which is the price of safety.